Running e- in the proton driver superconducting linac

P. Piot,
Fermilab/NICADD photoinjector laboratory

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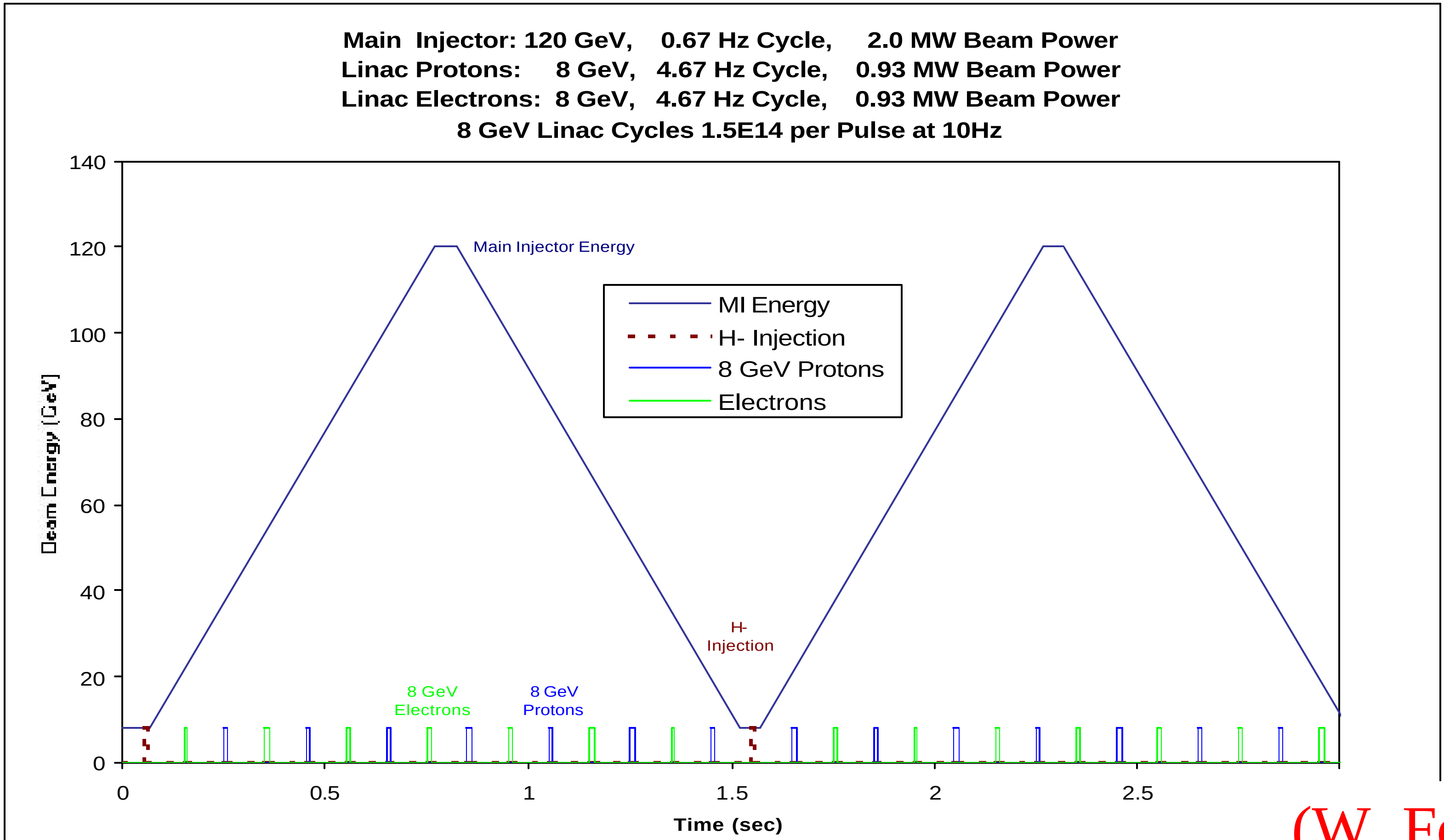
Running e- in the PD linac

- H- beam duty cycle is low (0.67 Hz) can use linac during free time to accelerate other species
- e- bunch train rep. rate 4.67 Hz (TESLA LC 5 Hz), bunch train duration 1 ms OK



(W. Foster)

Possible applications of e-

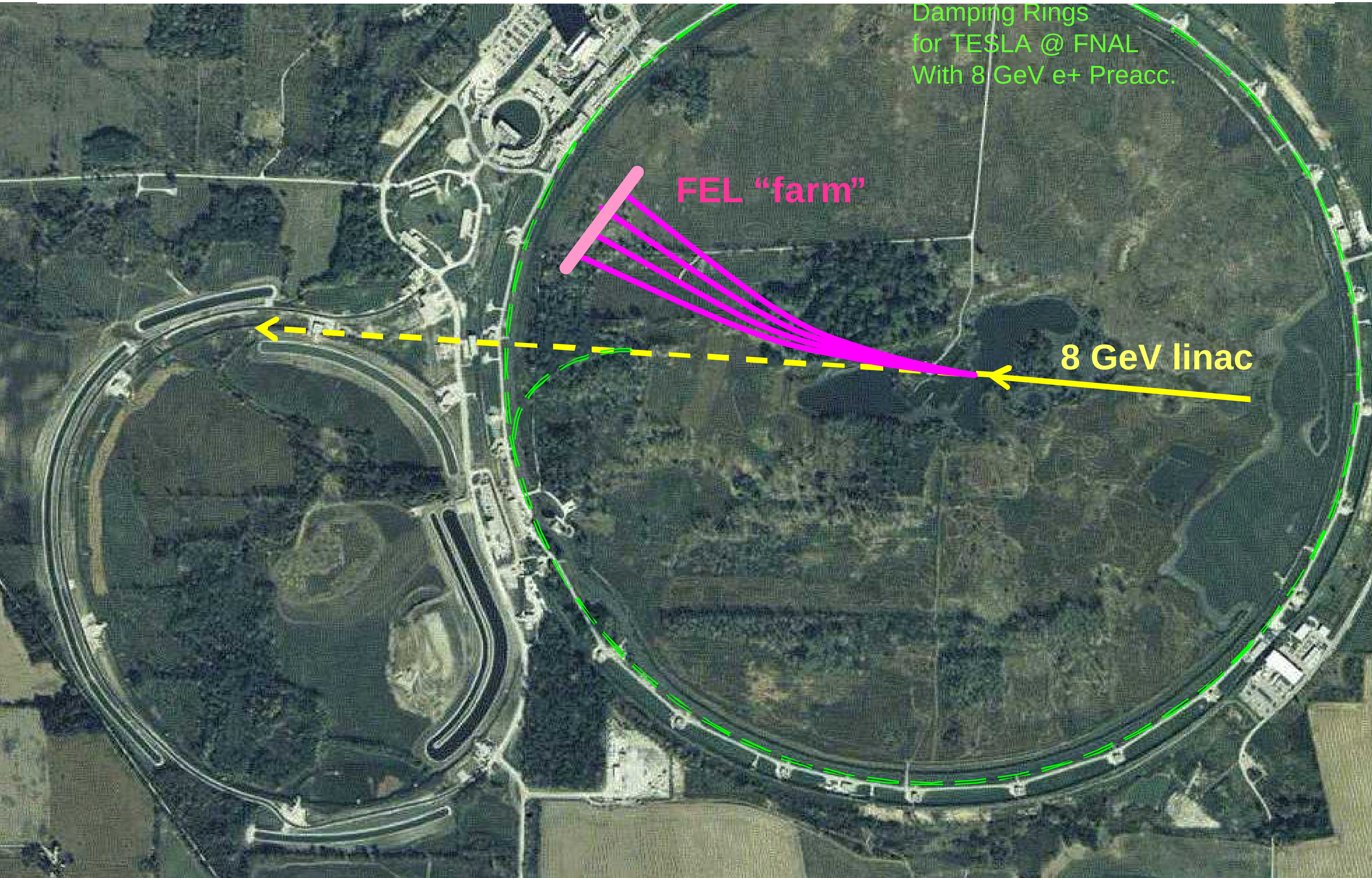
•Production of e- to ~6-8 GeV for ILC R&D purposes (5 GeV is the current injection energy in damping ring)

•Possible injection into TeV tunnel hosting a small damping ring (FNAL lattice design of 6 km damping ring): either e- injection or e+ injection (with conversion target)

•Possible production of short-wavelength photon beam using the single-pass free-electron laser concept

•R&D in advanced accelerator physics [test new acceleration schemes (e.g. laser-based acceleration etc…), new light source concept (e.g. Smith-Purcell radiation source)]

Possible applications of e-



Linear collider type applications

•**Optimization of a round beam electron injector for linear collider:** 5 GeV is the current energy for the injector (ILC) before injection in a damping ring

•**Could produce e+:** optimize e+ conventional technique and inject e+ beam in damping ring

•**Optimization of flat beam injector:** test how far can we push the method (currently transverse emittance ratio of 80 at FNPL)

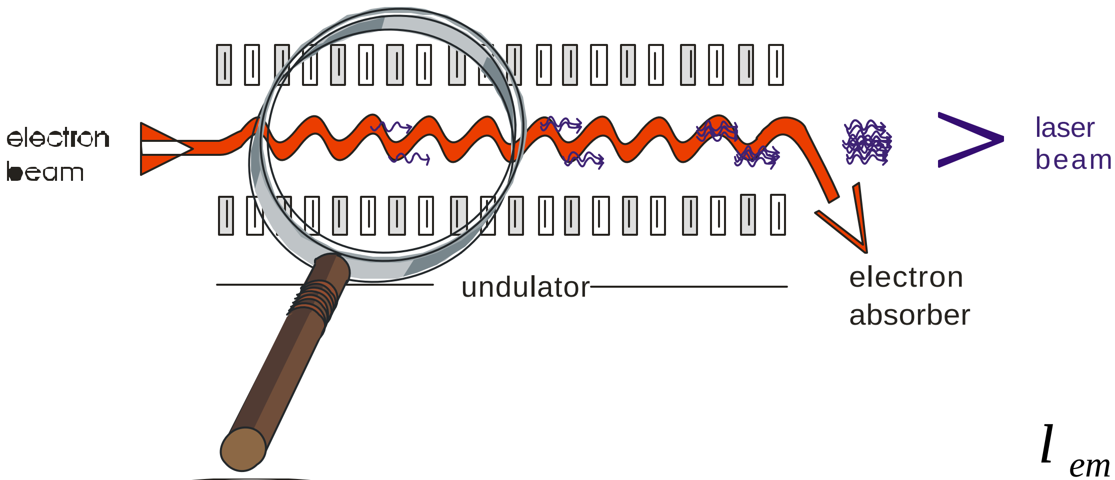
Typical LC injector parameters (TESLA type design):

$\beta\gamma\varepsilon$=5-10 mm-mrad,

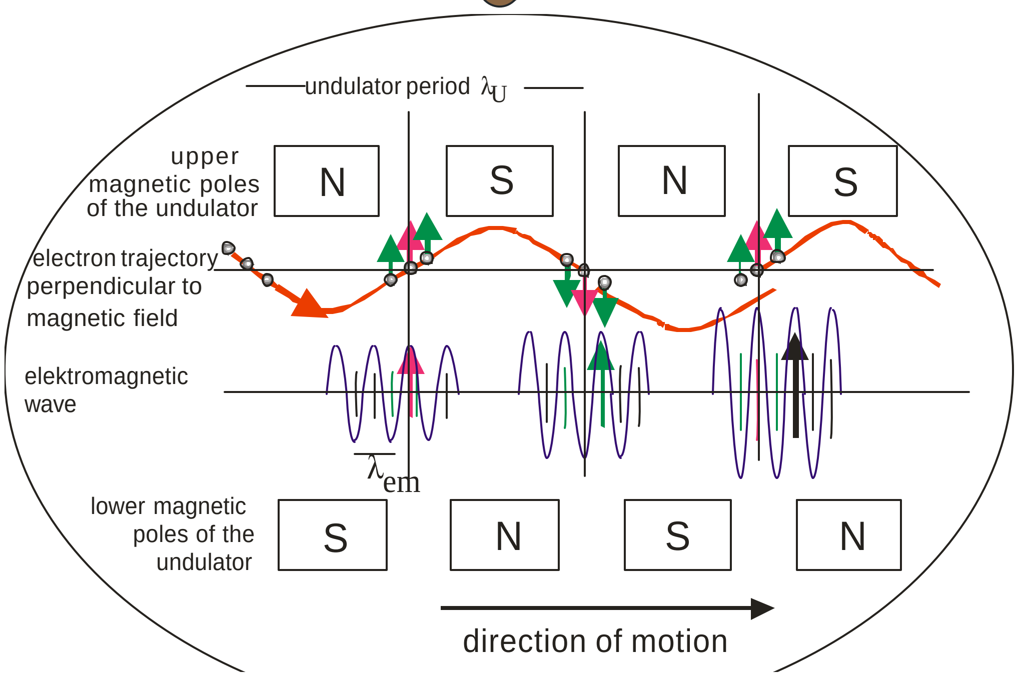
Q/bunch= 3.2 nC,

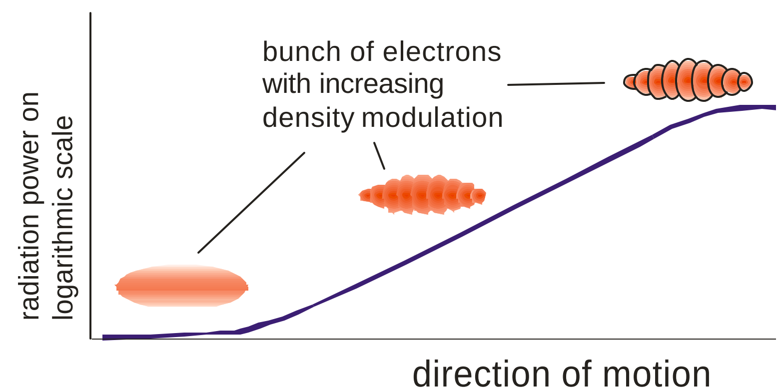
σ_z=0.3 mm (after damping ring compressor)

Free-electron laser type applications



$$l_{em} = \frac{l_u}{2g^2}\left(1 + \frac{K^2}{2}\right)$$





(J. Rossbach DESY)

Free-electron laser type applications

Energy:

$$l_{em} = \frac{l_u}{2g^2}\left(1 + \frac{K^2}{2}\right)$$

für λ_{em}= 1 Å: E ≈ 20 GeV

Energy width:

Narrow resonance → $\sigma_E/E = 10^{-4}$

⇔ Small distortion by wakefields

⇒ super conducting linac ideal!

Straight trajectory in undulator:
ultimately < 10 µm over 100 m

Gain Length:

$$L_g = \frac{1}{\sqrt{3}}\left[\frac{2mc}{m_0 e}\frac{g^3 s_r^2 l_u}{K^2 \hat{I}}\right]^{1/3}$$

Beam size:

$\sigma_r \approx 40$ µm ⇔ high electron desity for maximum interaction with radiation field

Emittance $\varepsilon = \lambda/4\pi$

need special electron source to accelerate the beam before it explodes due to Coulomb forces

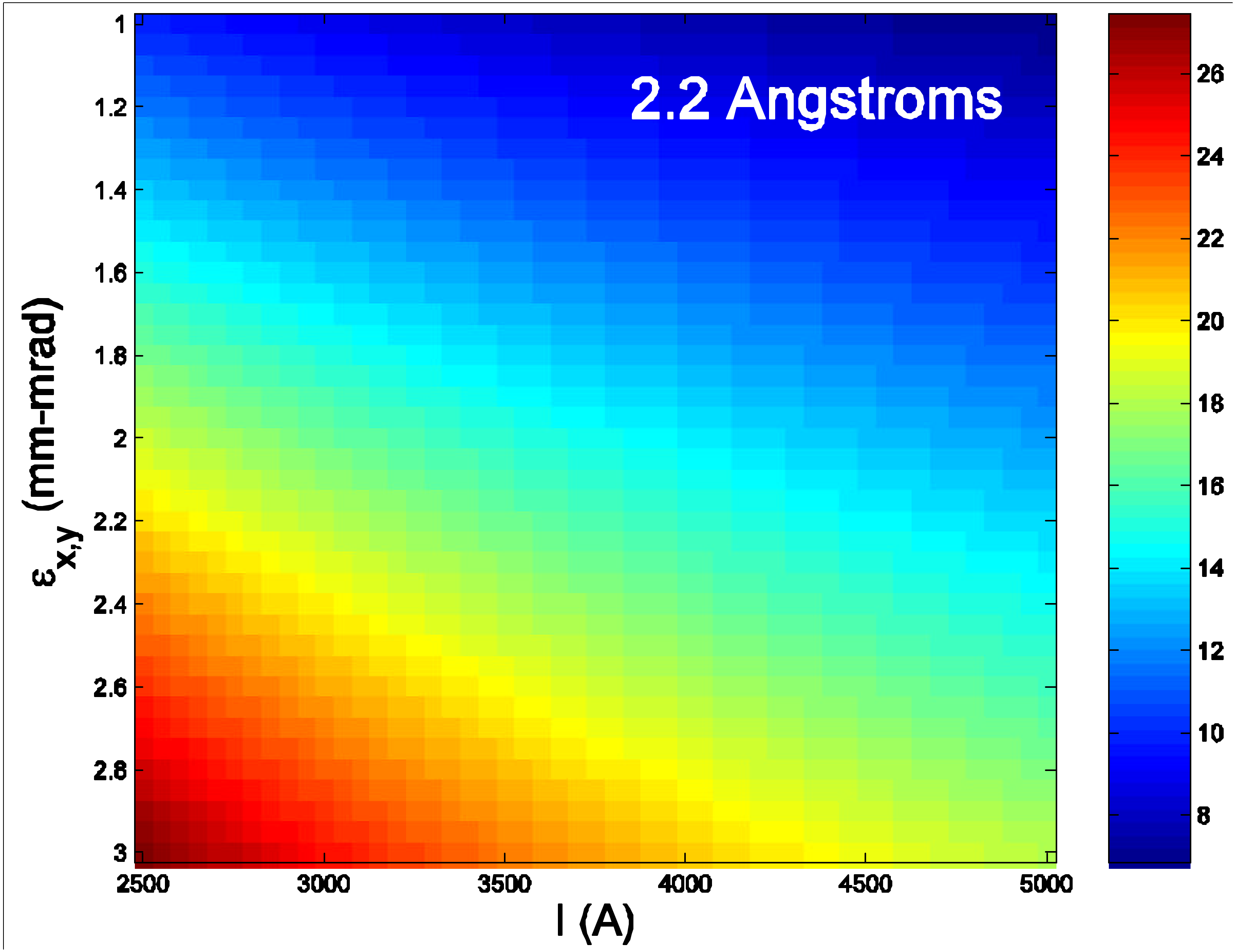
Peak current inside bunch:

$\hat{I} > 1$ kA

feasible only at ultrarelativistic energies, otherwise ruins emittance ⇒ bunch compressor

(J. Rossbach DESY)

Exple for a 6 GeV beam (K=1, λ_u=3cm)



Ingredients

Both linear collider and free-electron lasers require similar beam parameters. (FEL are more demanding on bunch length/peak current)

- High brightness electron source (maybe at a later stage polarized?)
- Injection scheme in the main linac
- Bunch compressor to enhance the peak current
- Extraction scheme

The accelerator physics challenges

•Coulomb “explosion” of e- bunch at low energy requires a proper optimization/choice of electron injector

$$F_{\perp}, F_{\parallel} \propto O\left(\frac{1}{g^{2}}\right)$$

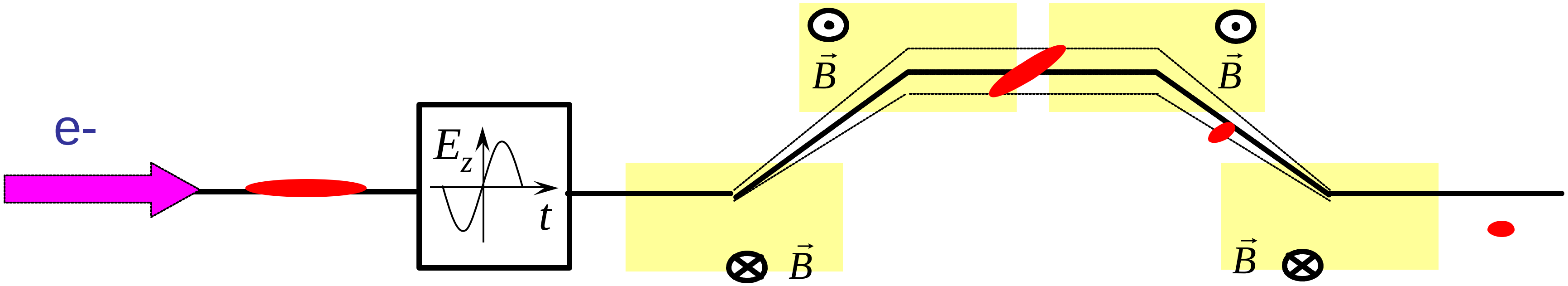
compromise between energy and charge density…

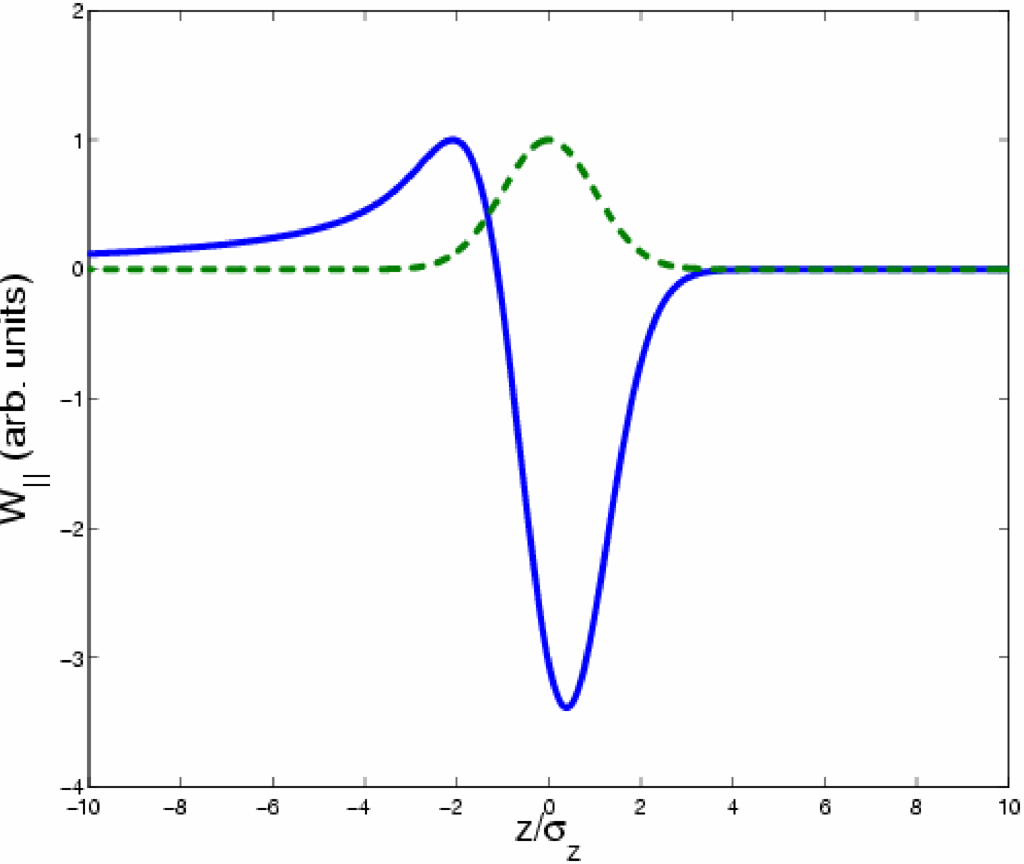
•Electron interaction with environment and with its own radiation in bends has to be included in the design considerations, e.g. coherent synchrotron radiation:

$$E_{\parallel} \propto O\left(\frac{1}{r^{2/3} s_{z}^{4/3}}\right)$$

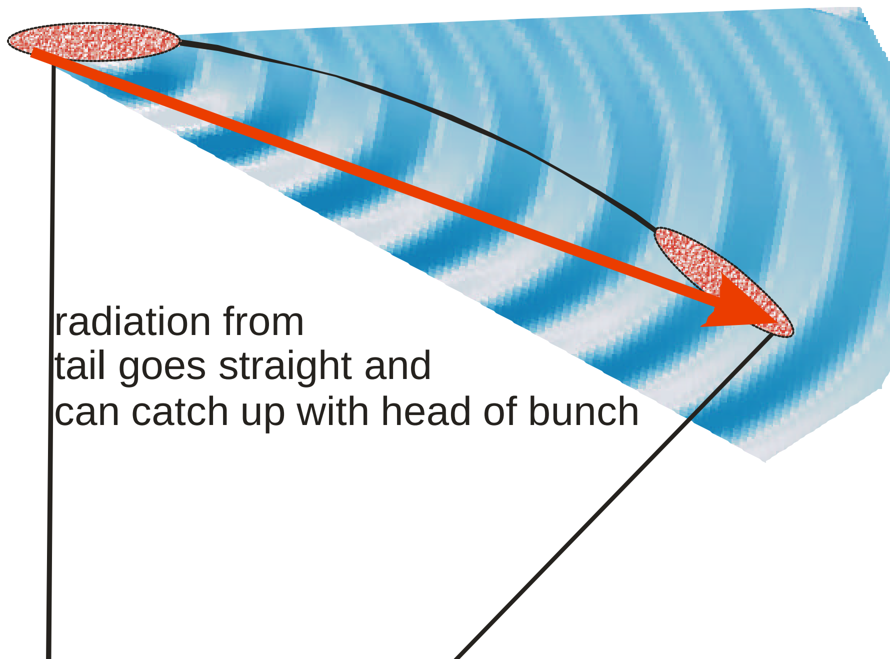
compromise between bunch length, bending radius,…

Bunch compression



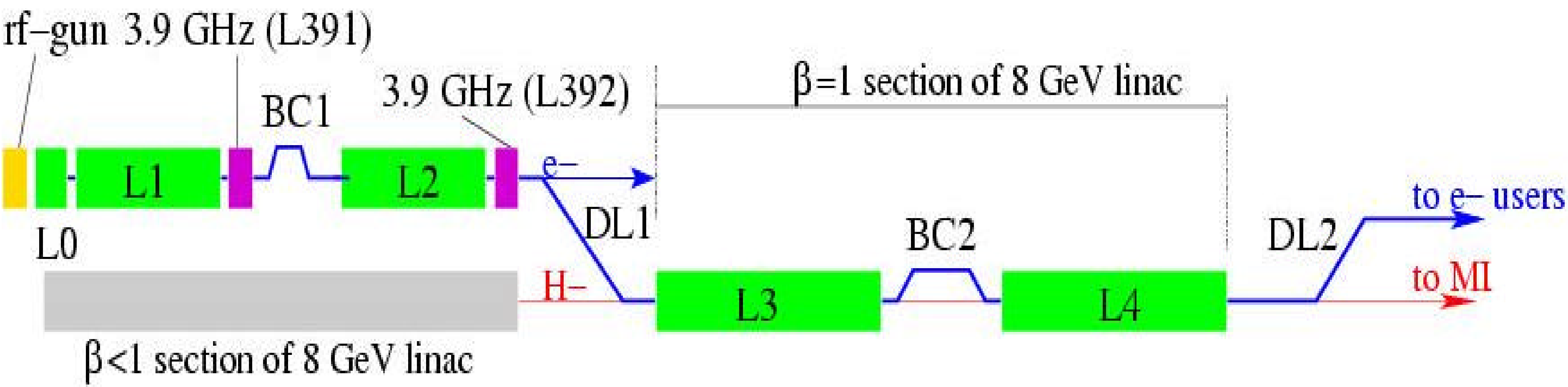


very powerful microwave radiation
with λ >~ bunch length if
bunch length << size of vacuum chamber



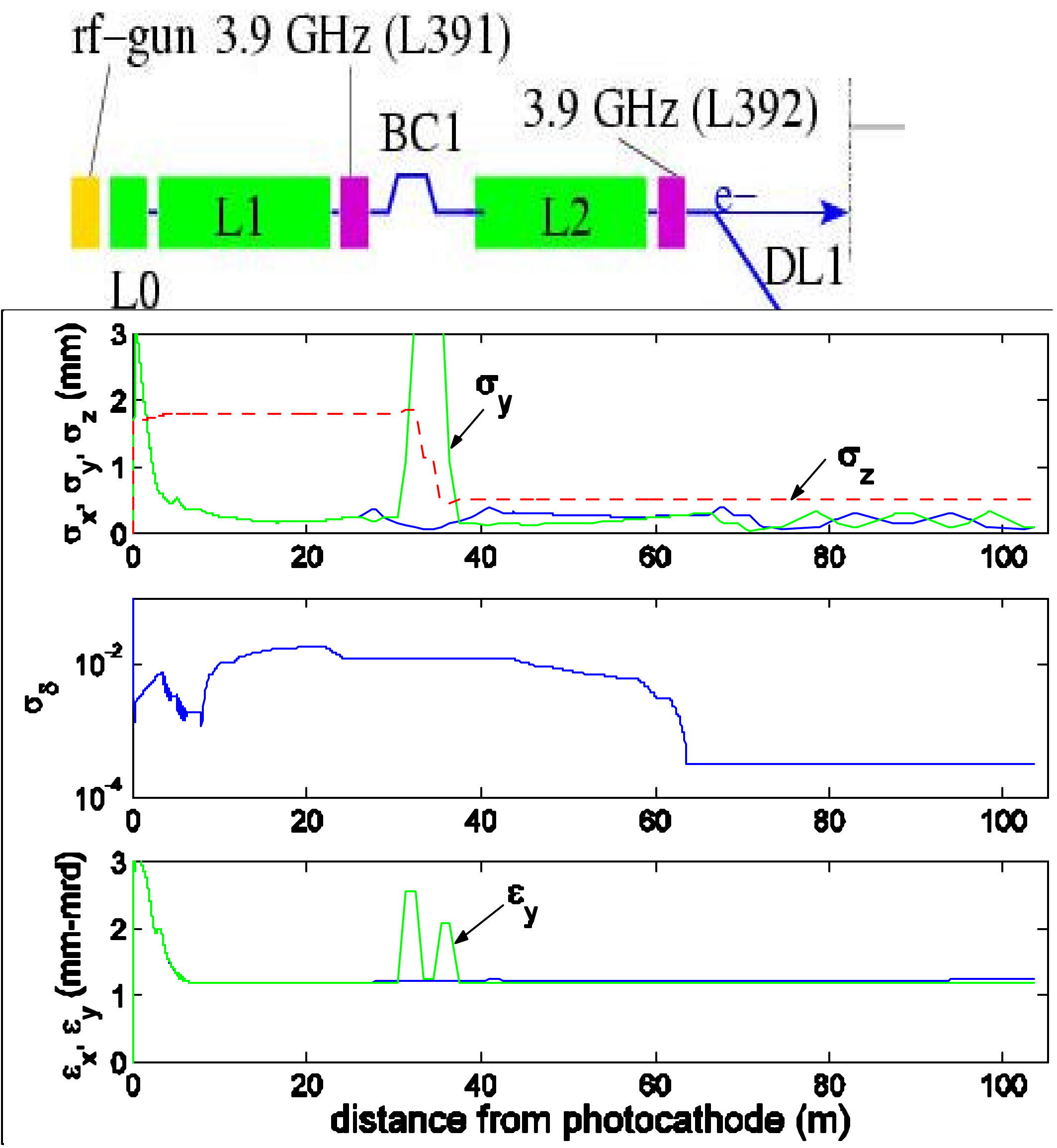
radiation from
tail goes straight and
can catch up with head of bunch

JUN04-design

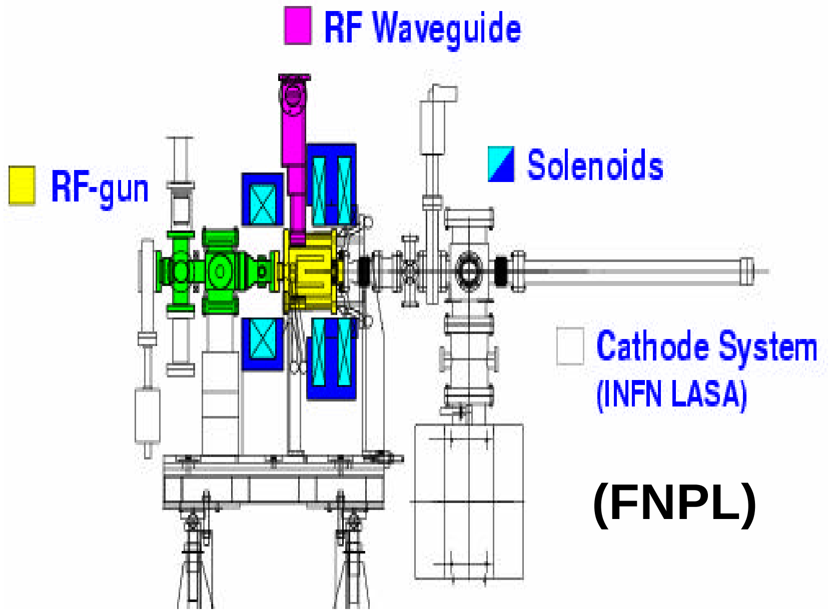


- β<1 section of the proton driver not used for e- acceleration: since e- are produced with β=1
- Off-axis electron source with injector installed above part of the β<1 section of the PD linac
- Extraction not worked out depends on details and/or other requirements

JUN04-design: injector

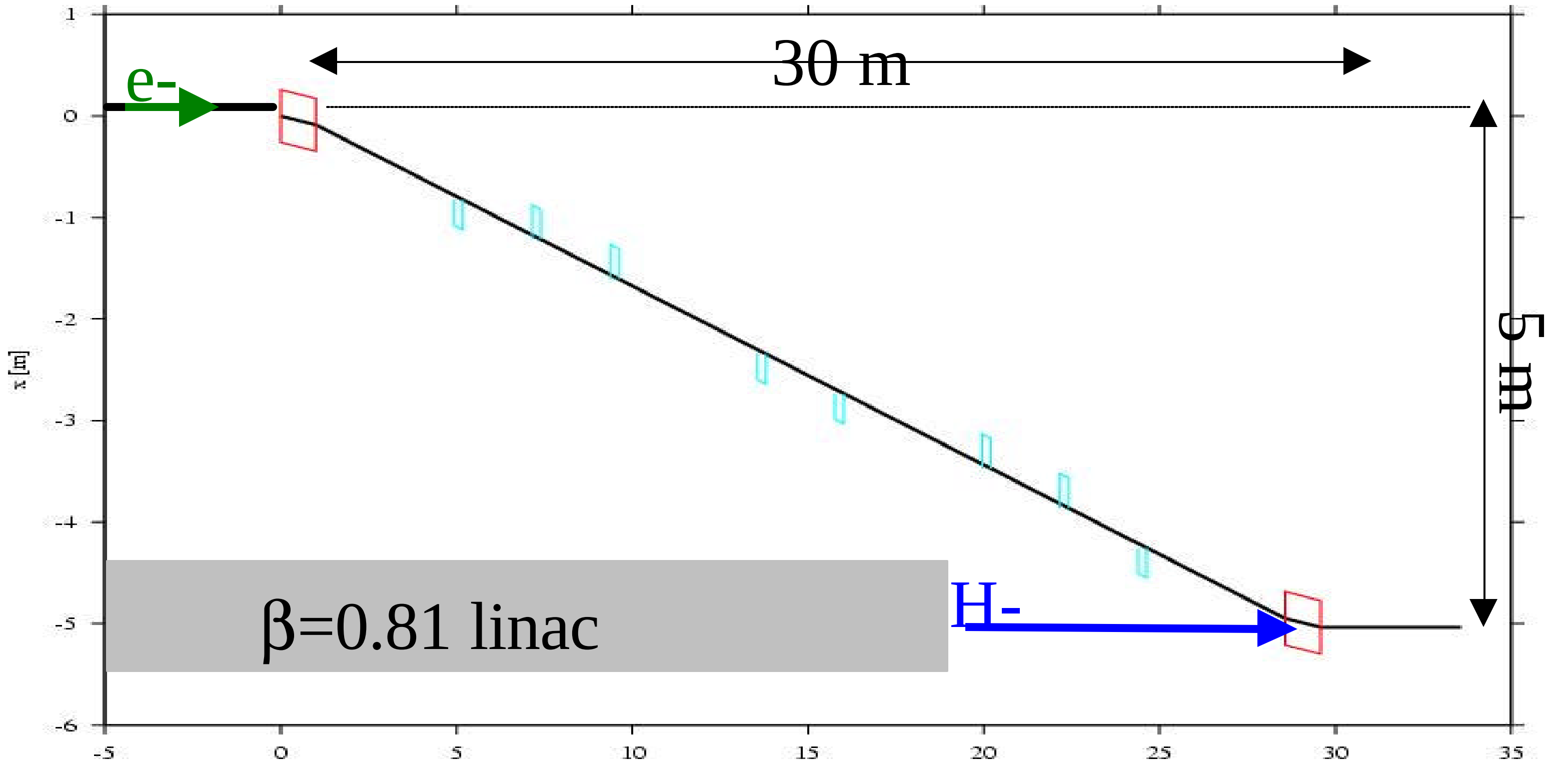


- Beam produced in a photoemission e- source

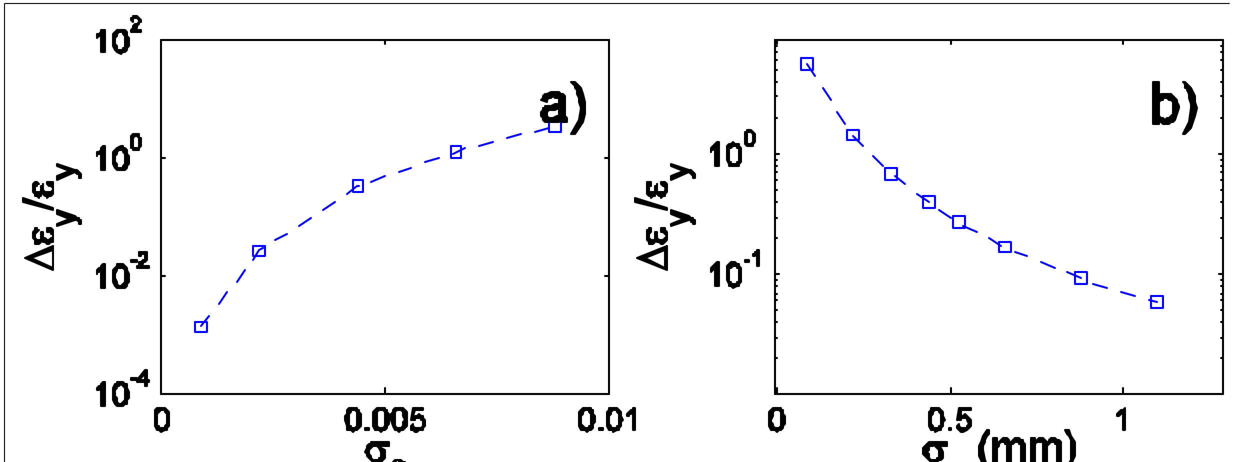


- Accelerated up to 340 MeV
- Injected in the main linac using a “dogleg” injection scheme

JUN04-design: injection dogleg



•Dogleg optimized for minimization of chromatic and CSR effects

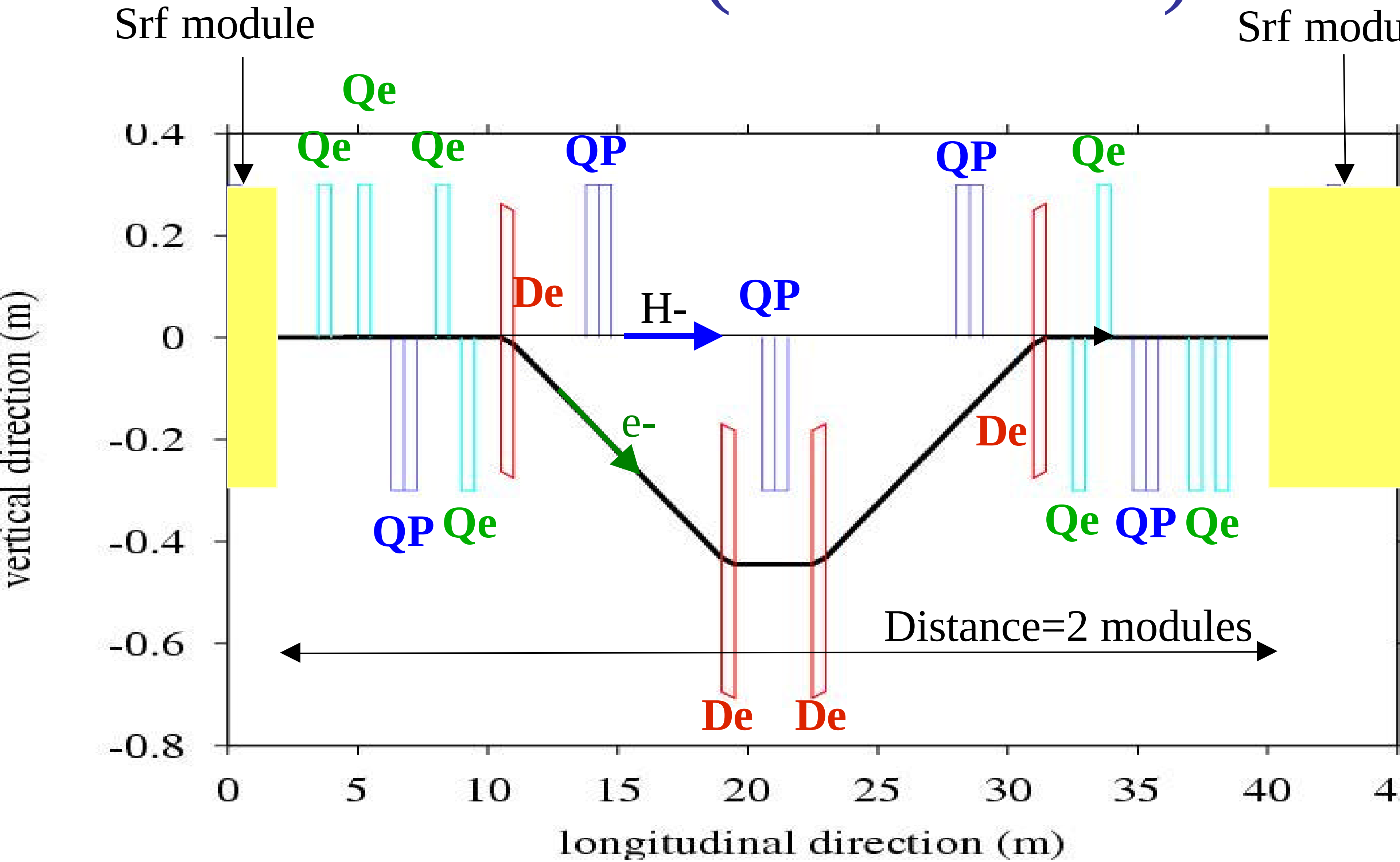


JUN04-design: injector perfromances

parameter	value	units
laser injection phase	44	rf-deg
laser radius on cathode	0.75	mm
laser flat top length	20	ps
laser rise time	2	ps
E-peak on cathode	60	MV/m
L0 accelerating voltage	12.5+25	MV
L0 phase	0 (on-crest)	rf-deg
L1 accelerating voltage	200	MV
L1 phase	-26 off-crest	rf-deg
L391 accelerating voltage	28.4	MV
L391 phase	+155 off-crest	rf-deg
L2 accelerating voltage	200	MV/m
L2 phase	0 (on-crest)	rf-deg
L392 accelerating voltage	28.0	MV
L392 phase	90 (0-crossing)	rf-deg
reduced energy γ	782.5	-
charge Q	1	nC
bunch length σ_z	516	μm
frac. energy spread σ_δ	3.3×10^{-4}	-
norm. emit. $\tilde{\varepsilon}_x$	1.24	mm-mrd
norm. emit. $\tilde{\varepsilon}_y$	1.20	mm-mrd

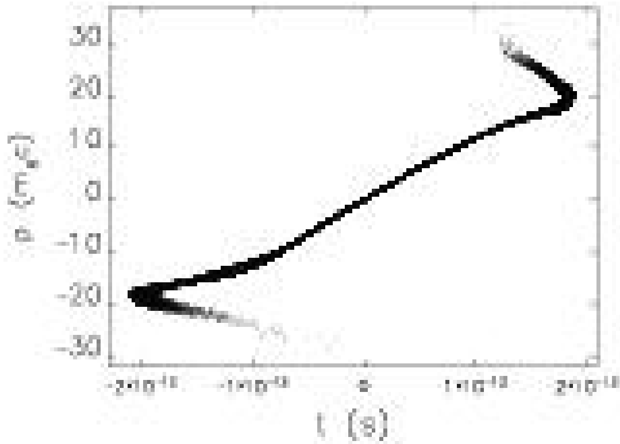
Table 1: Nominal settings for the rf elements and photocathode drive laser, and beam parameters downstream of DL1 (bottom part of table)

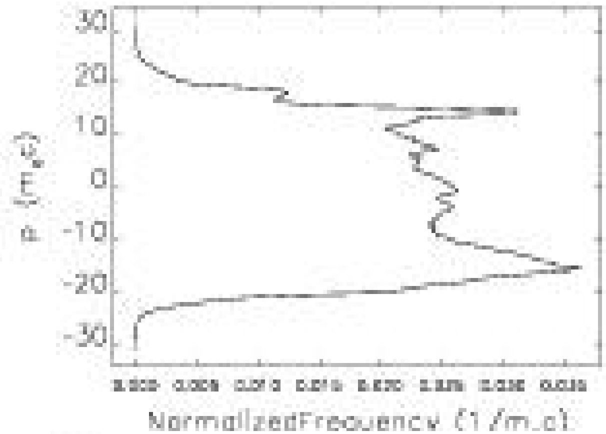
JUN04-design: bunch compressor in main linac (at 800 MeV)

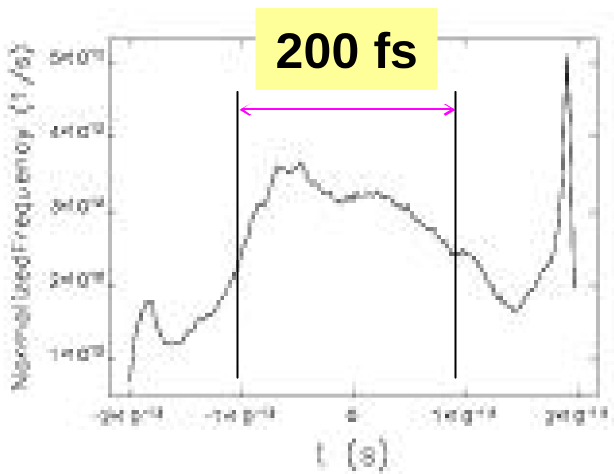


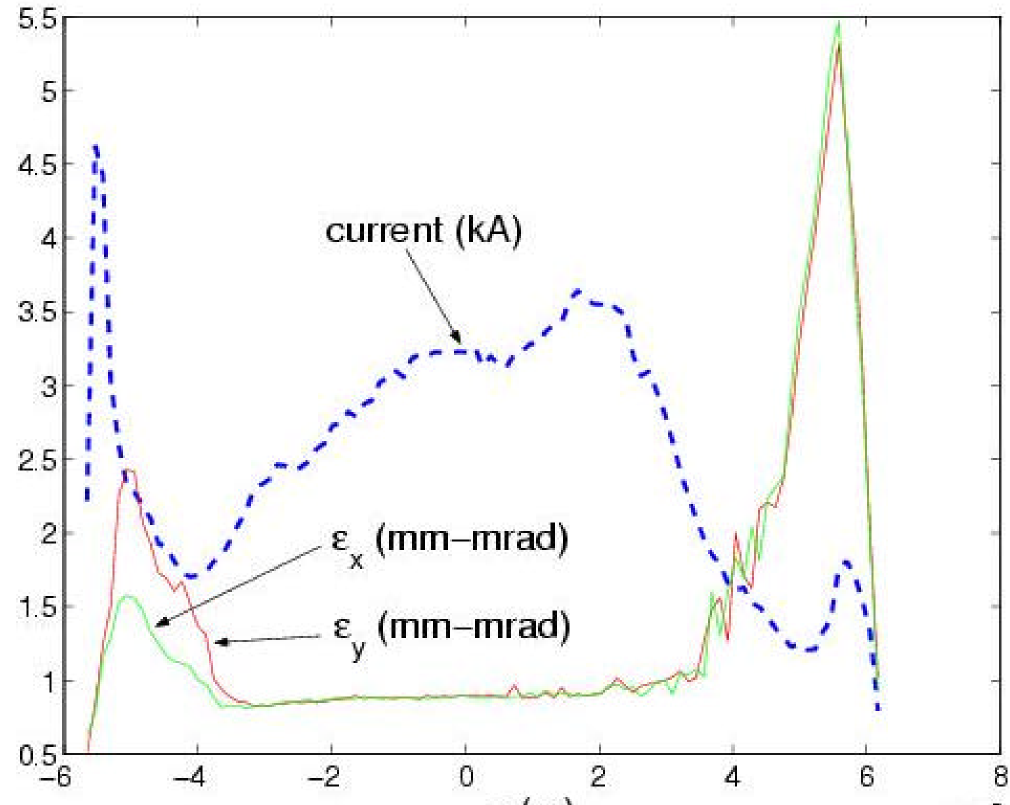
QP: Quads for p; Qe and De Quads + Dipoles for e- (pulsed?)

JUN04-design: parameter at ~6 GeV







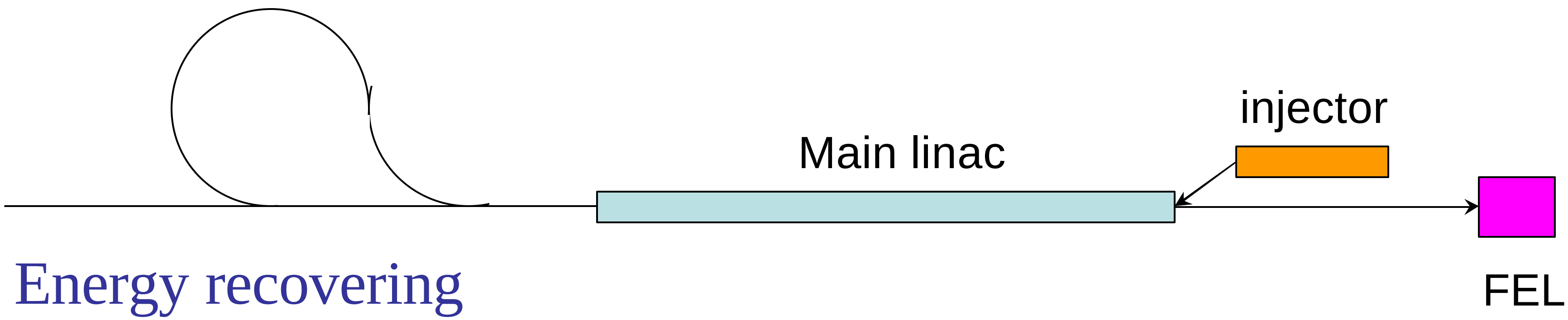


- Can produce beam parameters similar to state-of-art light sources proposal

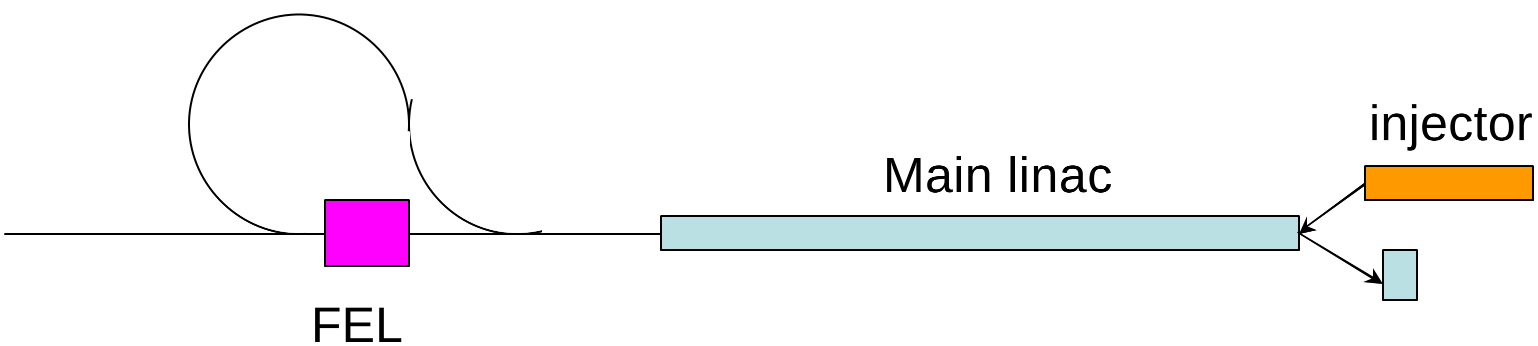
Next step: recirculation with tear drop loop?

Use an arc similar to TESLA damping ring to return e- beam (same idea as *Sekutovicz et al. PRSTAB Jan 2005*)

•Energy doubler



• Energy recovering



Summary

•With two minors modifications of the proton driver linac (an off-axis electron injector, and the insertion of a bunch compressor magnetic chicane in the main linac) electron beams with parameter similar to state-of-art linac driver for future light sources can be achieved

•The exact design and study on proton beam impact still needs some iteration (e.g. precise location of the bunch compressor)

•Possible recirculation of e- beam using the tear drop loop design for either energy doubling or energy recovering will be studied